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Radar Cross Sections of Surface Ships at Grazing Incidence
[Unclassified Title]

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Target Characteristics Branch

November 18, 1971

NAVAL RESEARCH LABORATORY
Washington, D.C.

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ABSTRACT
[Unclassified]

The radar-cross-section (RCS) values of seven classes of surface ships have been determined at grazing incidence at frequencies of 1300, 2800, and 9225 MHz for horizontal polarization and for vertical polarization at 9225 MHz. Measurements were performed at the Chesapeake Bay Division at NRL as the ships proceeded in \ circular orbit. The ships used for the measurements were the DD 764, ᴜᴇG 6, DDG 19, LPD 1, DE 1027, DLG 26, and AFS 5. In addition, measurements were made on the DLG and AFS in C band at 5500 MHz for both horizontal and vertical polarizations. Cross-section values were plotted as a function of ship aspect in the form of polar profiles. The profiles plotted were the 20, 50, and 80 percentile values of the RCS distribution function, which were determined for 2-degree azimuth increments.

PROBLEM STATUS

This is a final report on measurements made to date. Measurements on additional ship classes will continue.

AUTHORIZATION

NRL Problem R06-44
Project No. S3315

RADAR CROSS SECTIONS OF SURFACE SHIPS
AT GRAZING INCIDENCE
[Unclassified Title]

INTRODUCTION

(U) The radar-cross-section (RCS) values of seven classes of surface ships have been determined using the NRL dynamic measurement radar (1,2). The ships are the DD 764, *Lloyd Thomas;* DE 1027, *John Willis;* DDG 19, *Tattnall;* DEG 6, *Julius A. Furer;* LPD 1, *Raleigh,* DLG 26, *Belknap;* and AFS 5, *Concord.* The 20, 50, and 80 percentiles of the RCS distribution function are plotted in dB above 1 square meter. The values cover a 360-degree aspect profile in 2-degree azimuth increments for grazing incidence.

(U) Horizontal polarization was employed at frequencies of 1300 MHz, 2800 MHz, and 9225 MHz for all tests. Vertical polarization data were obtained at 9225 MHz for all ships, with the exception of DE 1027. In addition, results are reported at 5500 MHz for the DLG and AFS for vertical and horizontal polarizations.

DATA ACQUISITION

(U) Data were taken as the ship orbited in a 1000-yard-diameter circle around a point approximately 9500 yards from the radar site. The radar is about 100 feet above the water; thus the average angle of incidence was 0.2 degree. At the selected speed of 6 knots the azimuth aspect angle changed at the rate of approximately 0.5 degree per second.

(U) To accurately determine the azimuth aspect angle, the ship's heading was continuously recorded during the data runs by use of a synchro-to-digital converter connected to the ship's gyrocompass. The digital output of the converter was combined with the output of a WWV-synchronized time-code generator and recorded on tape. A similarly time-coded tape at the radar site contained the radar range and the train and elevation angles. Thus, by time alignment of the tapes in a computer combined with suitable programming, the azimuth aspect angle could be determined to an accuracy of ±0.2 degree. If the gyrocompass is determined to have an offset, the aspect angle is adjusted as required.

(U) The system was calibrated by use of a balloon-borne 6-inch sphere. This calibration process was used before the first orbit, between orbits, and at the conclusion of the tests when possible. Prior to the initial calibration, the receiver systems were checked extensively by means of calibrated remote beacons.

RADAR SYSTEM

(U) The measurement system used for most of the tests consisted of three similar pulsed radars operating from a common pedestal. Prior to the measurements on the U.S.S. *Belknap* and the U.S.S. *Concord,* a fourth transmitter operating in C band was added to the system. In operation, all transmitters are pulsed simultaneously. Table 1 lists some of the basic system characteristics.

(U) The receiver systems use no agc and operate with an instantaneous dynamic range of 40 dB. The dynamic range is further increased by use of remotely controlled rf attenuators in each receiver channel. In addition fixed rf attenuators were manually inserted

Table 1(U)
Basic System Characteristics

Band	Frequency (MHz)	Peak Radiated Power (kW)	Pulse Width (μsec)	Pulse Rate (pps)	Beamwidth, E × H Plane (degrees)	Transmitted Polarization	Received Polarization
L	1300	250	1	500	7.5 × 6	H, V	Same as transmitted
S	2800	250	1	500	3.5 × 3	H, V	Same as transmitted
C*	5500	250	1	500	3 × 3	RC, LC, H, V	Parallel and orthogonal components
X	9225	250	1	500	3 × 3	RC, LC, H, V	Parallel and orthogonal components

*Available for measurements on the *Belknap* and *Concord* only.

prior to data runs. These were used to account for the gross changes in size of various targets. Local-oscillator power is supplied by fixed oscillators rath·: than by a klyson system using afc. The overall passband of the receiver is flat within ±1/2 dB over 5 MHz.

(U) The pulse-to-pulse backscatter signals are recorded digitally to facilitate reduction. Video outputs from the receivers are stretched and quantized to ten bits for recording on a 16-track recorder. In addition the range, train and elevation angles, step attenuator values, run number, and timing information are recorded on the same tape. Other data recorded at the site consist of the WWV time code, range, and train and elevation angles on a computer formatted tape, pulse-to-pulse video on 35-mm film, 16-mm boresight film, a chart recording of the detected stretched video, and a simultaneous voice commentary from all operator stations.

DATA REDUCTION

(U) Most of the data reduction is performed by a high-speed digital computer. The reduction process is divided into four steps and is outlined in Fig. 1. The first step in the processing is the generation of a magnetic tape containing the aspect solution using the time-coded tapes of the radar coordinate information and the ship's heading. This tape and the pulse-by-pulse data are then used to generate a calibrated pulse-by-pulse tape of RCS. In this process, calibration factors determined from the 6-inch-sphere measurements are applied, attenuation inserted in the receivers to maintain signals within the system dynamic range is converted to a 0-dB reference, and range compensation is applied. The pulse-by-pulse RCS tape is then segmented into 2° aspect cells, and the RCS distribution function for the cell is formed. The percentiles of interest are read and punched on cards together with aspect identification and the number of pulses from which the percentiles were determined. The final step in the processing is the compilation of results from individual data runs or orbits. All percentiles from corresponding aspects are averaged using the ratio of pulses used for each value to the total number of pulses as a significance weight. Having determined the weighted mean, the RCS profile is plotted.

RESULTS

(U) Table 2 lists the ships used for the tests, some characteristics of each ship (3), and the figure numbers for the ships' photographs and RCS profiles. The 20, 50, and 80

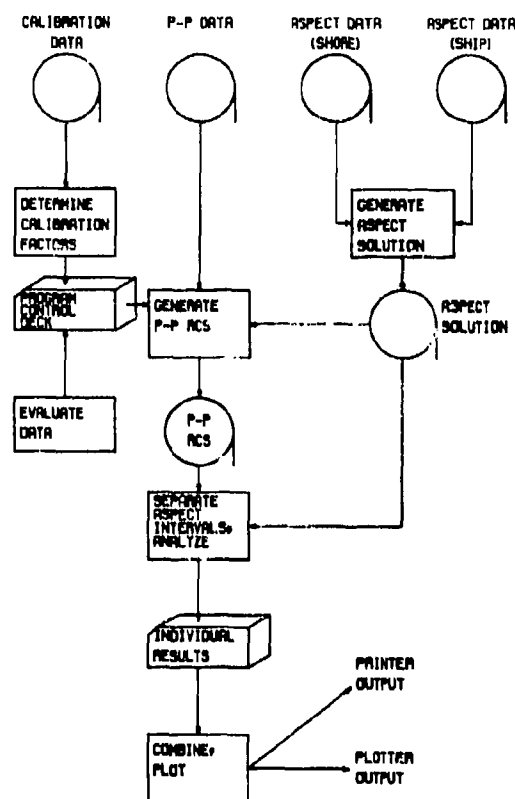Fig. 1(U) - Outline of the computer routine used in processing the data. (P-P indicates pulse-by-pulse.)

Table 2(U)
Ship Characteristics and Index to Figures

Designation	Name	Full-Load Displacement (tons)	Overall Length (ft)	Overall Width (ft)	Fig. Nos. of Photos	Fig. Nos. of Data
DD 764	Lloyd Thomas	3500	390.5	40.9	2	3-6
DEG 6	Julius A. Furer	3425	414.5	44	7a, 7b	8-11
DDG 19	Tattnall	4500	432	47	12	13-16
LPD 1	Raleigh	13,900	521.8	84	17	18-21
DE 1027	John Willis	1914	314.5	36.8	22a, 22b	23-25
DLG 26	Belknap	7930	547	54.8	26	27-38
AFS 5	Concord	16,500	581	7)	39a, 39b	40-45

percentile values of the RCS distribution function are plotted in the figures listed in the last column and are designated by a circle (O), a triangle (Δ), and a cross (+) respectively. The kth percentile denotes that (100 - k)% of the received pulses exceed the plotted value. All cross-section values are plotted in decibels above 1 square meter. The shipboard search radar antennas were rotating with transmitters in standby for all tests.

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(U) For several ships photographs taken prior to the data runs show helicopter hanger doors facing the stern partly open (Figs. 7b, 22b, and 39b). It is not known if the status of the doors changed during the measurements. Having the doors open could affect the RCS values at aspects near the stern.

(U) Readings of the ship's inclinometer were relayed to shore during tests subsequent to the DD and DEG measurements to establish that the orbiting conditions did not create an appreciable dynamic list (heel). When list angles were reported, the cause in most cases except for the *Belknap* was determined to be an unbalance in the ship's ballast and not a function of direction of rotation. For the *Belknap*, RCS values are reported separately for the CW and CCW orbits. The ship had a static list to starboard of 1 degree and acquired a dynamic list of 1 degree to port during a CW orbit or to starboard during a CCW orbit. Thus the list was 0 degrees for CW orbits and 2 degrees to starboard for CCW orbits. During measurements on this ship the TR tube in the L-band system changed characteristics, exhibiting a longer-than-normal recovery time. This causes high attenuation of signals at the sphere calibration range (2 kyds) but has little effect on the target echo at the measurement range (9 to 10 kyds); therefore calibration data were lost for this frequency. These data were calibrated indirectly by use of a signal generator, thereby reducing the confidence in results at 1300 MHz.

(U) Measurements on the DE 1027 were conducted during a period of extremely limited visibility. It was not possible to obtain a sphere calibration until the conclusion of the tests, and in addition the orbits were made 4000 yards from the radar instead of 9500 yards. Furthermore there was insufficient time to obtain X-band vertically polarized data due to deployment requirements placed on the ship.

CONCLUSIONS

(C) The ability to accurately define the RCS profile of a target depends on the accuracy to which the aspect angles can be determined. The method of determining the azimuth aspect, discussed previously, results in a maximum error of ±0.2 degree; however the elevation angle has not been measured to this accuracy. The static list of a ship during the measurement interval appears to alter the RCS for measurements at identical aspects off the port and starboard bow when the ship appears to possess a nearly symmetrical image. This is clearly evident in the results for the DEG given in Fig. 10, where median values are 53 dBsm and 38 dBsm for port and starboard 14-degree aspects respectively. This trend is evident through most aspects on this figure, although the differences are generally of the order of 6 dB. Still photographs taken prior to measurements indicate a list to port of approximately 2 degrees.

(C) At some aspects similar differences occur but appear to be the result of structural differences in the ship. Figure 25, the RCS of the DE for X band, is an example; RCS values for aspects of 200 to 220 degrees are generally 10 dB greater than for 170 to 150 degrees, probably because of the corners produced by alteration of the superstructure to locate a whaleboat on the starboard side as opposed to the smooth lines found on the port side.

(C) Comparison of the results on the *Belknap* for the case of 0 degrees elevation for X-band horizontal polarization (Fig. 31) and up to 2 degrees elevation (Fig. 32) shows a decrease in RCS values as the elevation angle increases. This decrease of RCS with elevation would be expected, since the center of the radar beam is no longer normal to the vertical members of the ship's superstructure and specular reflections are absent. It is felt intuitively that this trend would continue until elevation angles became large enough that corners formed by the deck and superstructure, and by the hull and water surface, would

cause RCS values to stop decreasing and begin increasing toward a maximum return near 45 degrees. The RCS values at angles near 45 degrees would probably not be as great as those at angles near grazing.

(C) The curves for the AFS (Figs. 40 through 45) show RCS peaks at 0, 90, 180, and 270 degrees which appear to be shifted by +2 degrees from the proper aspect angle. The only source of measurement error which would produce this effect is improper synchronization of either time-code generator. For an error of this magnitude the misalignment would be of the order of 5 seconds, and since an audio check of the synchronization of the two generators was made, it is believed that an unreported 2-degree error existed in the ship's gyrocompass. It is suggested, therefore, that all values in Figs. 40 through 45 be shifted by 2 degrees to correct for the apparent error.

ACKNOWLEDGMENTS

(U) The valuable assistance of A.E. March, D.C. Hut, C.E. Jedrey, Jr., P.A. Curran, and P. Ward in the system preparation and data acquisition phases of the program is gratefully acknowledged.

(U) The contributions of Lt. B.F. Boyce, Lt. J.C. Donahue and Mr. J. Ryon in the coordination of activities with the officers and crews of the cooperating ships are acknowledged.

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2. E.E. Maine, Jr., and F.D. Queen, "Radar Cross Section of Surface Ships" (Unclassified title, Confidential paper), Sixteenth Annual Tri-Service Radar Symposium Record, Sept. 1970 (Secret).
3. R.V.B. Blackman, compiler and editor, "Jane's Fighting Ships," McGraw-Hill, New York, 1968-1969.
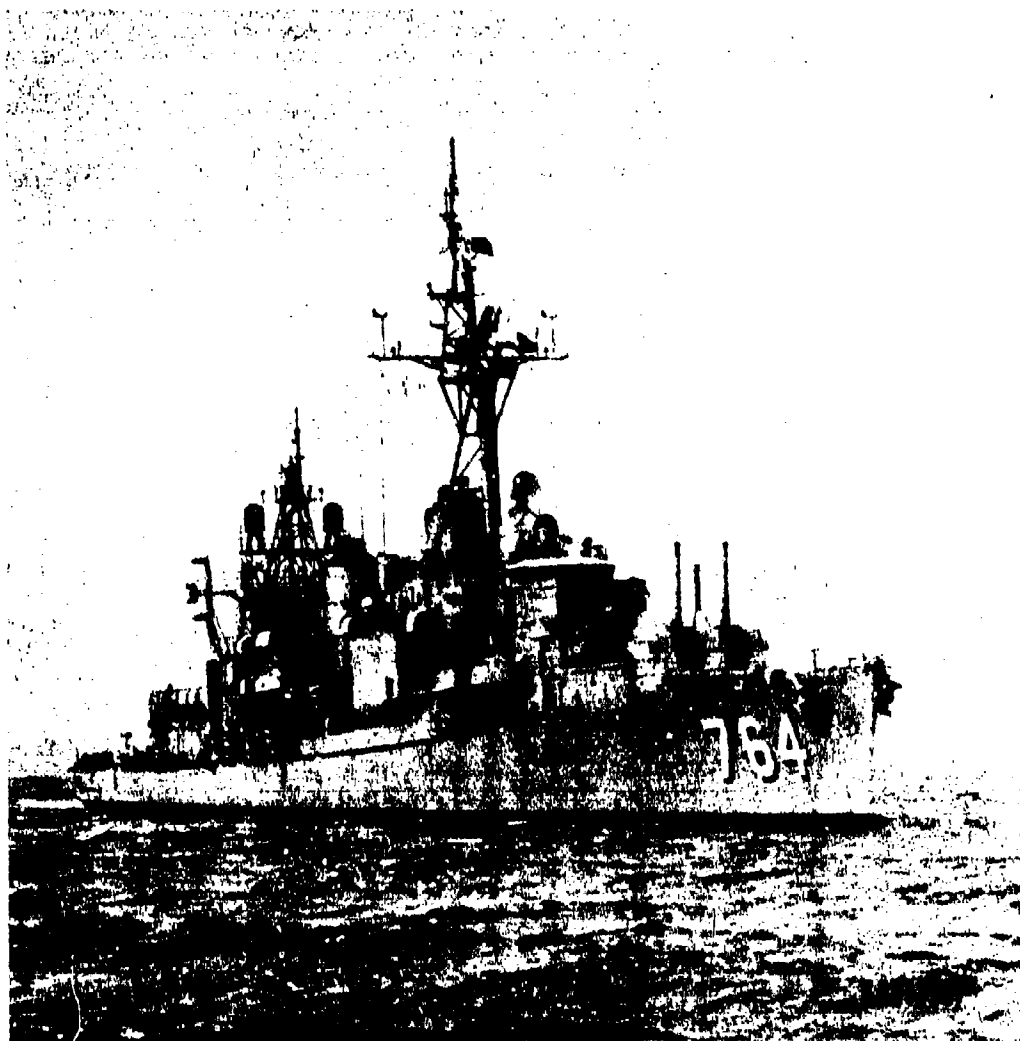
Fig. 2(U) - U.S.S. *Lloyd Thomas*, DD 764
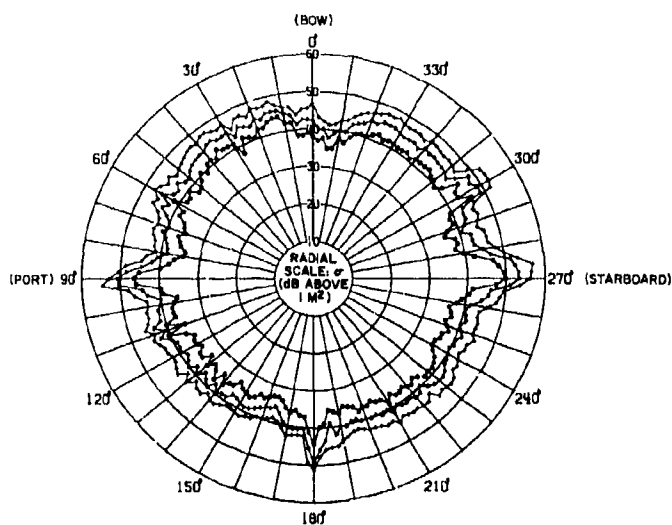
Fig. 3(C) - Radar cross section of the DD 764 at 1300 MHz for horizontal polarization. Shown are the 20, 50, and 80 percentile values of the RCS distribution function denoted by a circle (○), a triangle (△), and a cross (+), respectively.
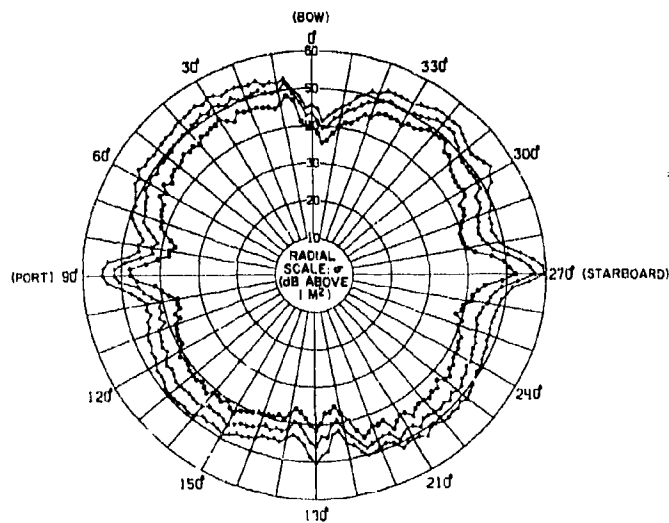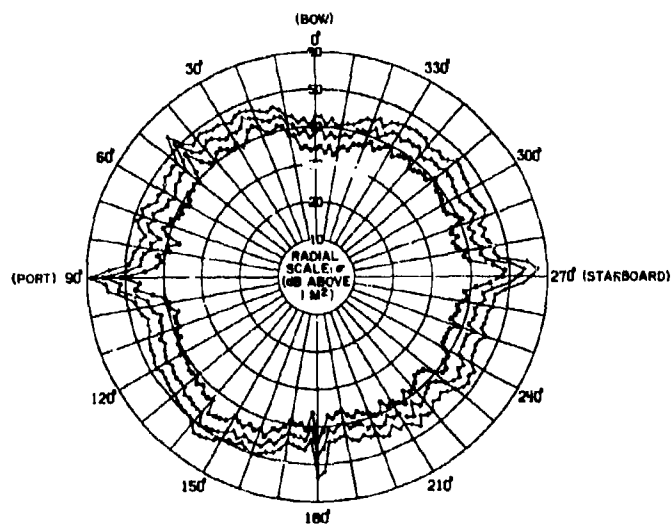

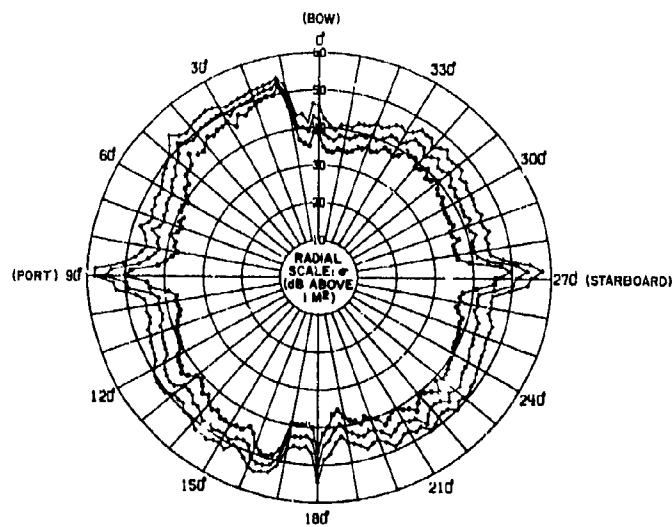Fig. 4(C) - Radar cross section of the DD 764 at 2800 MHz for horizontal polarization
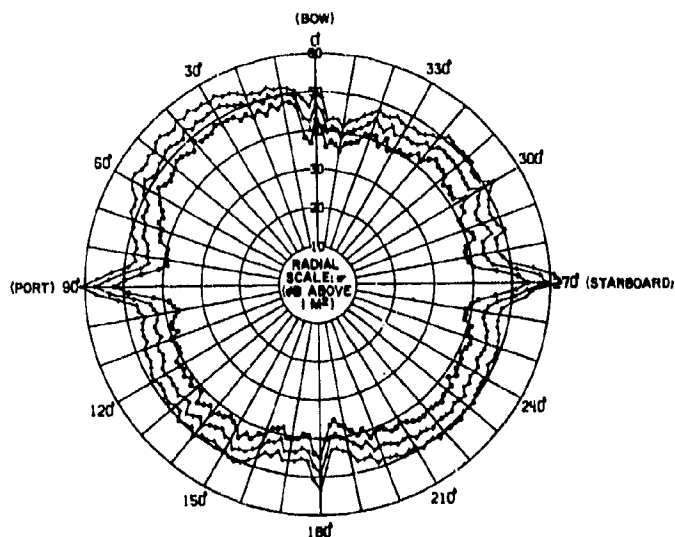
Fig. 5(C) - Radar cross section of the DD 764
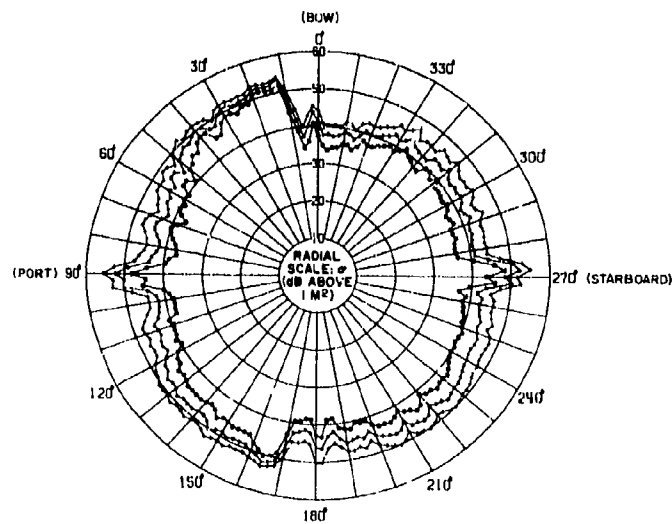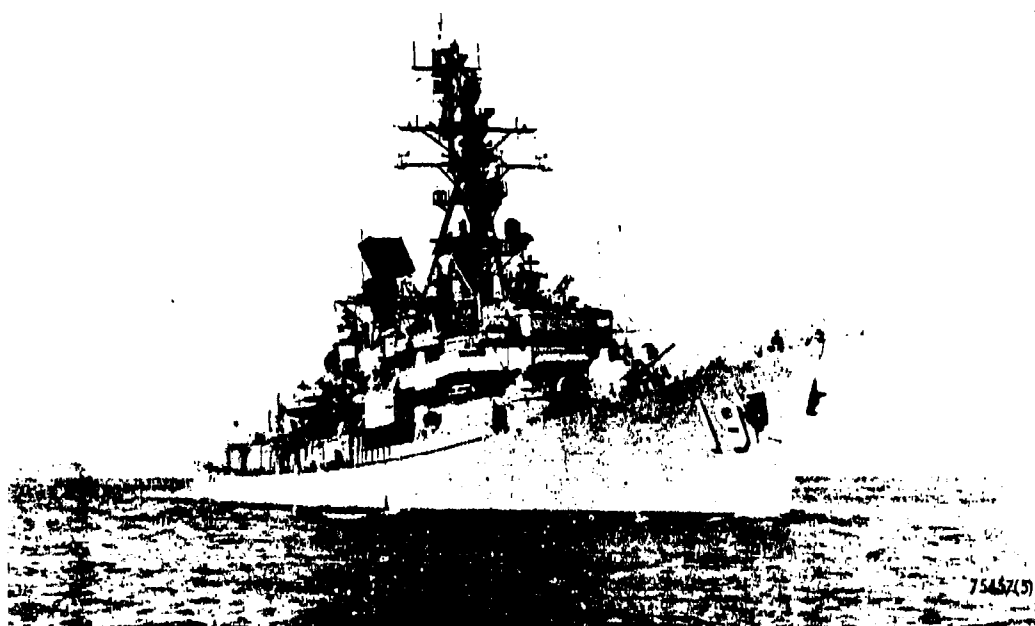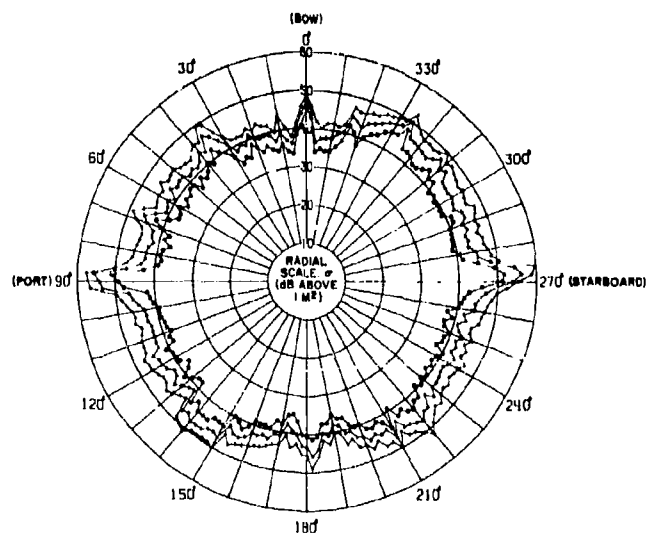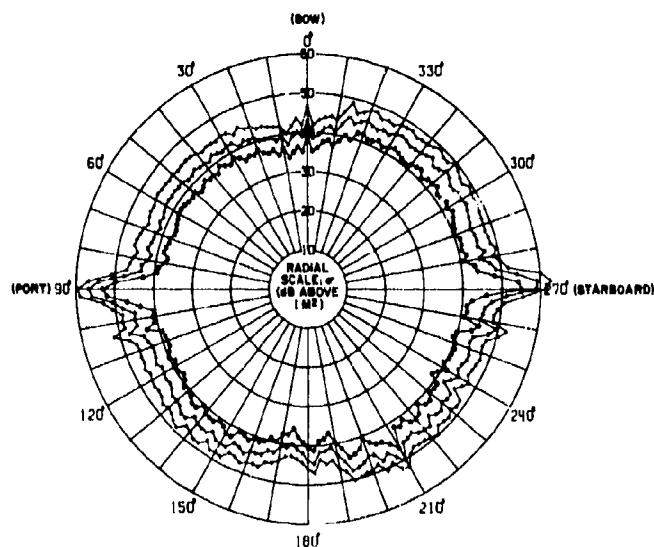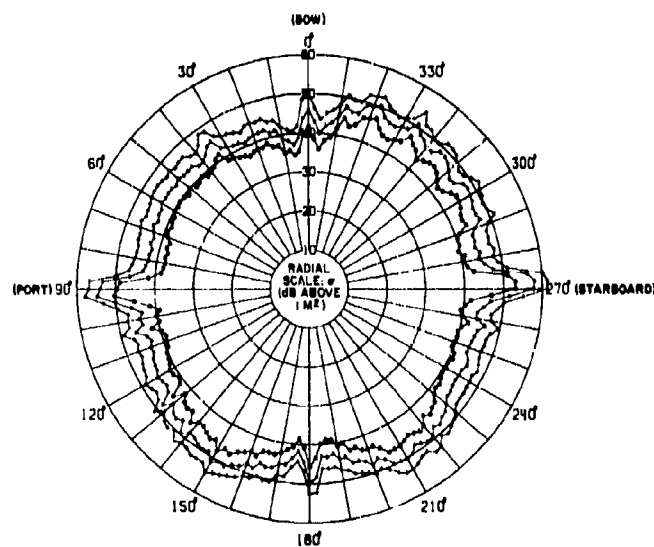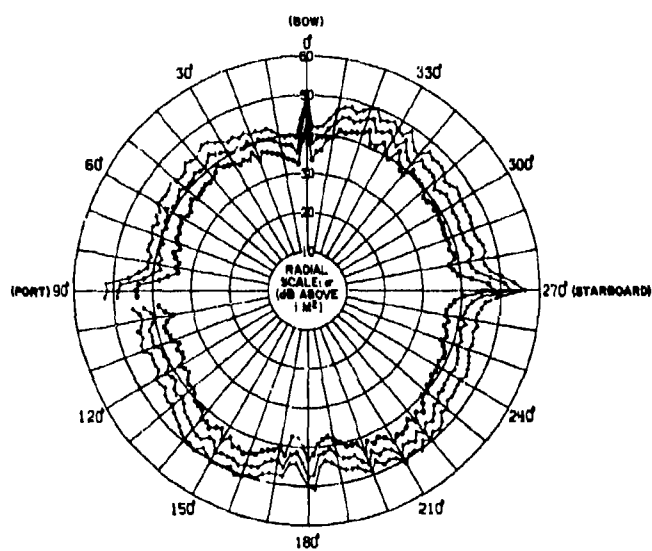at 9225 MHz for horizontal polarization
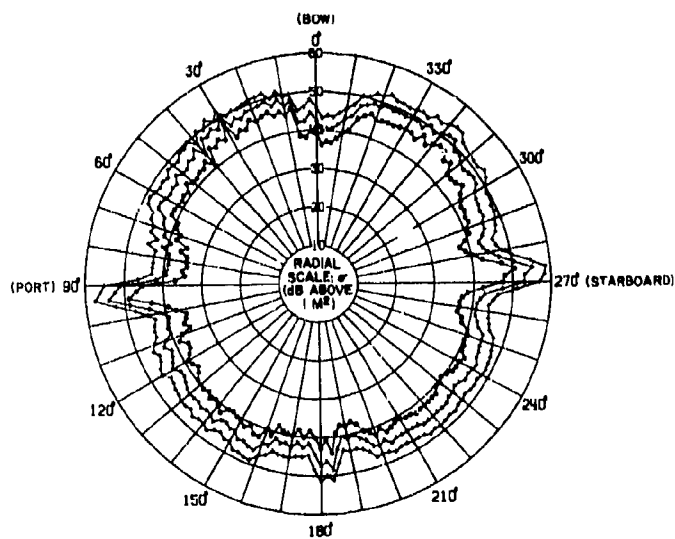
Fig. 6(C) - Radar cross section of the DD 764
at 9225 MHz for vertical polarization
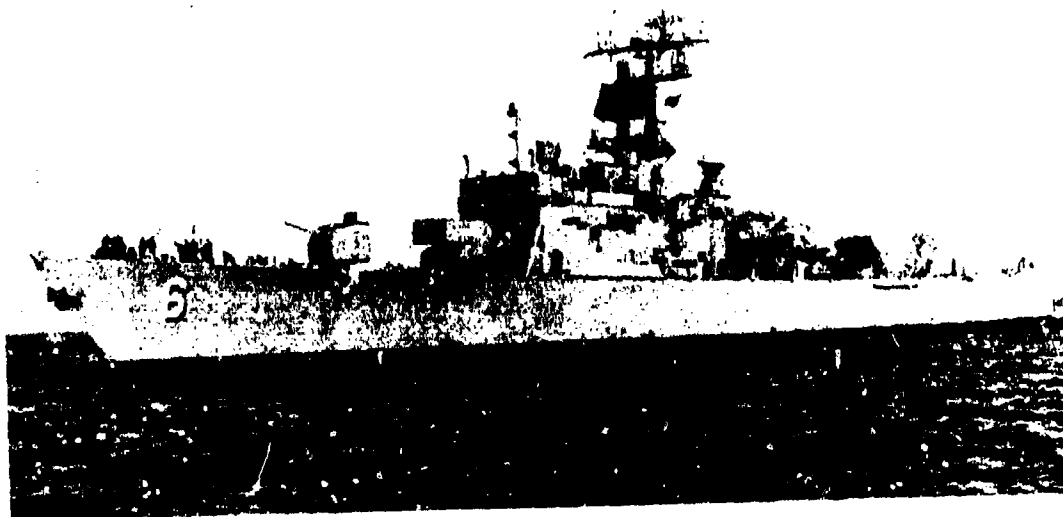
75239(7)

Fig. 7a(U) - U.S.S. *Julius A Furer*, DEG 6

75239(1)
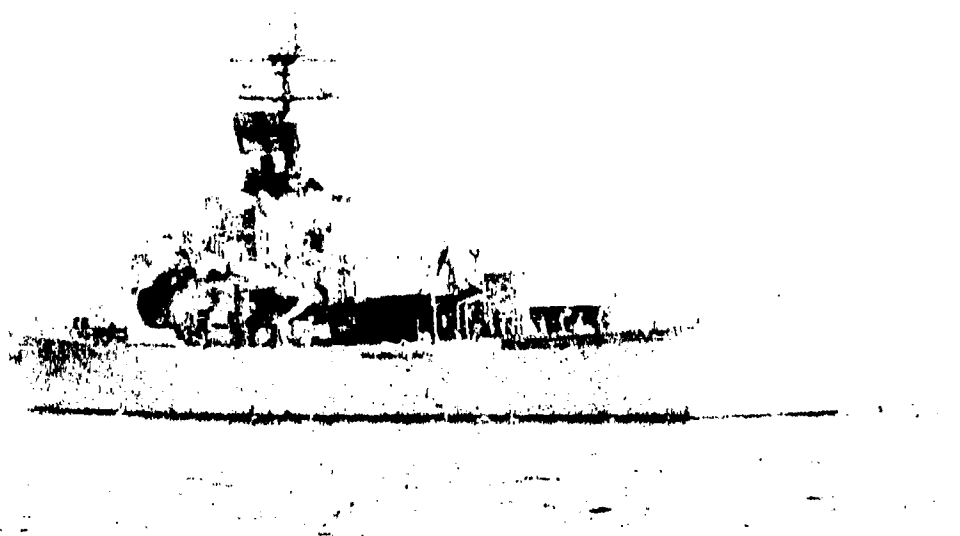
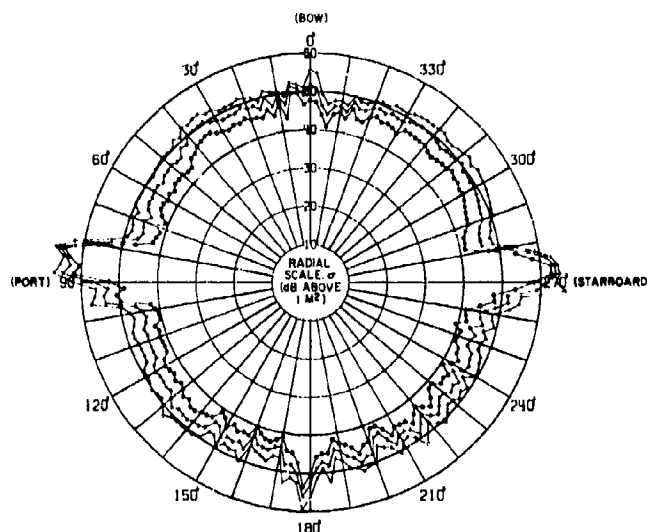Fig. 7b(U) - Port quarter view of the U.S.S. *Julius A. Furer*, DEG 6
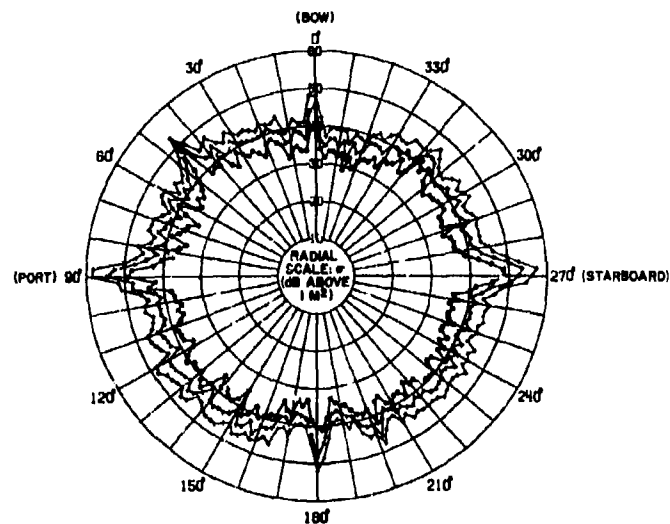
Fig. 8(C) - Radar cross section of the DEG 6 at 1300 MHz for horizontal polarization. Shown are the 20, 50, and 80 percentile values of the RCS distribution function denoted by a circle (○), a triangle (△), and a cross (+) respectively.
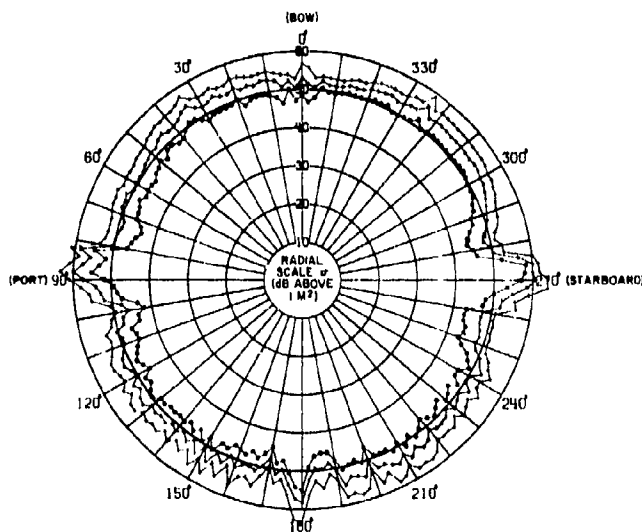

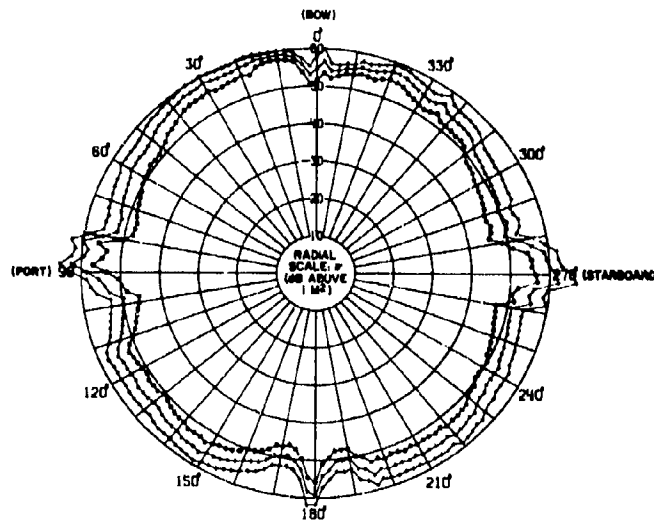Fig. 9(C) - Radar cross section of the DEG 6 at 2800 MHz for horizontal polarization

Fig. 10(C) - Radar cross section of the DEG 6
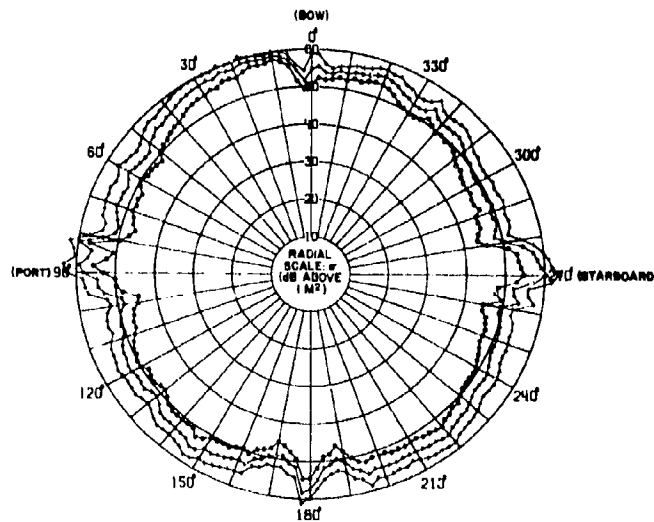at 9225 MHz for horizontal polarization

Fig. 11(C) - Radar cross section of the DEG 6
at 9225 MHz for vertical polarization

Fig. 12(U) - U.S.S. *Tattnall*, DDG 19

Fig. 13(C) - Radar cross section of the DDG 19 at 1300 MHz for horizontal polarization. Shown are the 20, 50, and 80 percentile values of the RCS distribution function denoted by a circle (○), a triangle (△), and a cross (+) respectively.

Fig. 14(C) - Radar cross section of the DDG 19
at 2800 MHz for horizontal polarization

Fig. 15(C) - Radar cross section of the DDG 19
at 9225 MHz for horizontal polarization

Fig. 16(C) - Radar cross section of the DDG 19
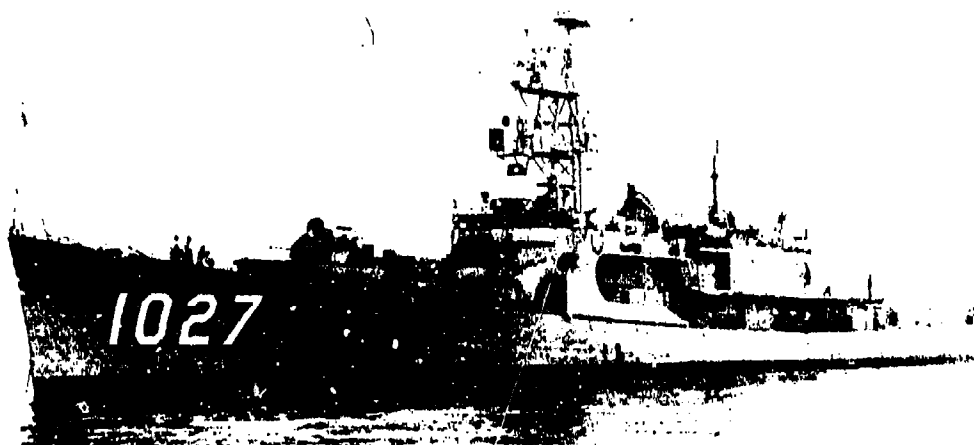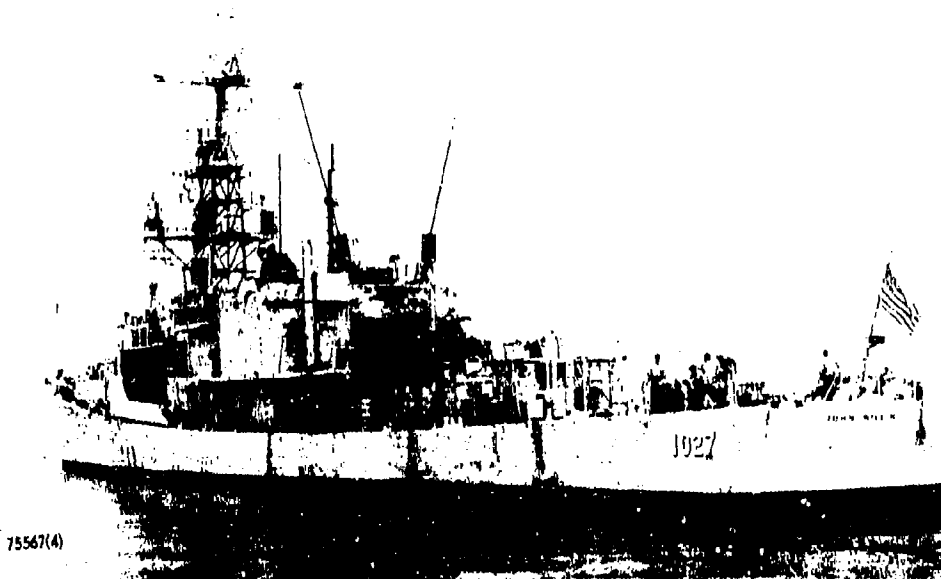at 9225 MHz for vertical polarization
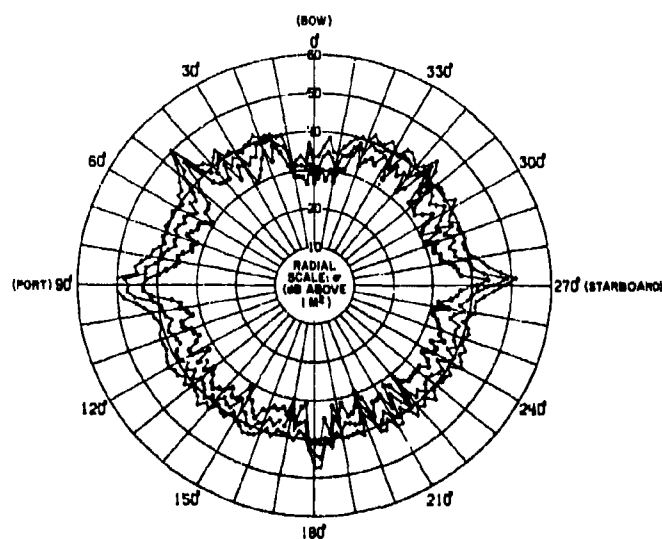
75523(5)
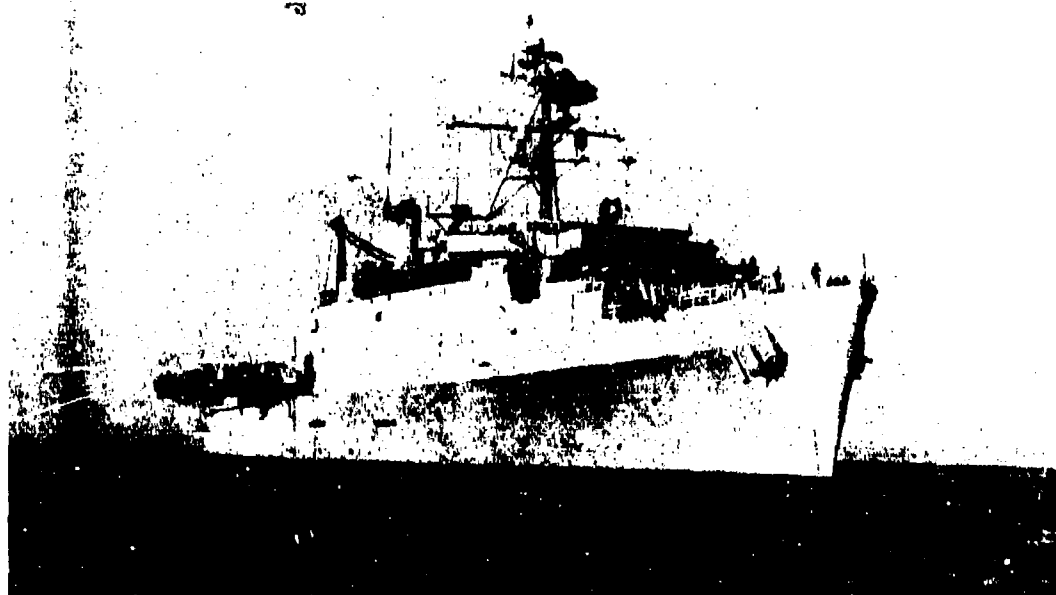
Fig. 17(U) - U.S.S. *Raleigh*, LPD 1

Fig. 18(C) - Radar cross section of the LPD 1 at 1300 MHz for horizontal polarization. Shown are the 20, 50, and 80 percentile values of the RCS distribution function denoted by a circle (○), a triangle (△), and a cross (+) respectively.
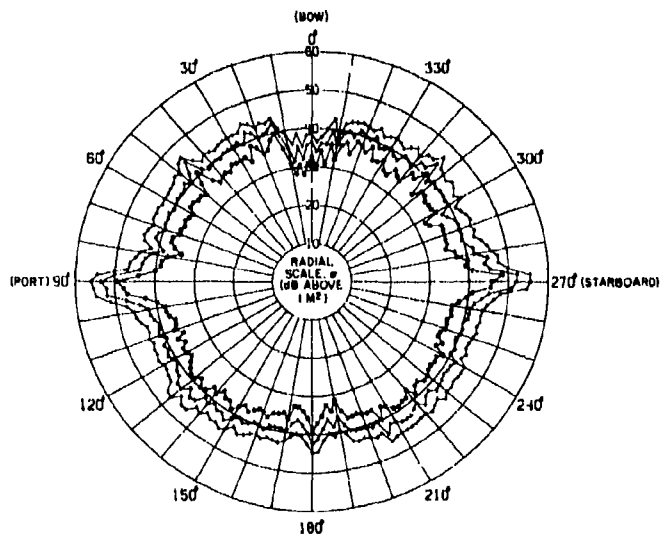
Fig. 19(C) - Radar cross section of the LPD 1 at 2800 MHz for horizontal polarization

Fig. 20(C) - Radar cross section of the LPD 1
at 9225 MHz for horizontal polarization

Fig. 21(C) - Radar cross section of the LPD 1
at 9225 MHz for vertical polarization

75567(7)

Fig. 22a(U) - U.S.S. *John Willis*, DE 1026

75567(4)

Fig. 22b(U) - Port quarter view of the U.S.S. *John Willis*, DE 1026

Fig. 23(C) - Radar cross section of the DE 1027 at 1300 MHz
for horizontal polarization   Shown are the 20, 50, and 80 per-
centile values of the RCS distribution function denoted by a
circle (○), a triangle (△), and a cross (+) respectively.

Fig. 24(C) - Radar cross section of the DE 1027
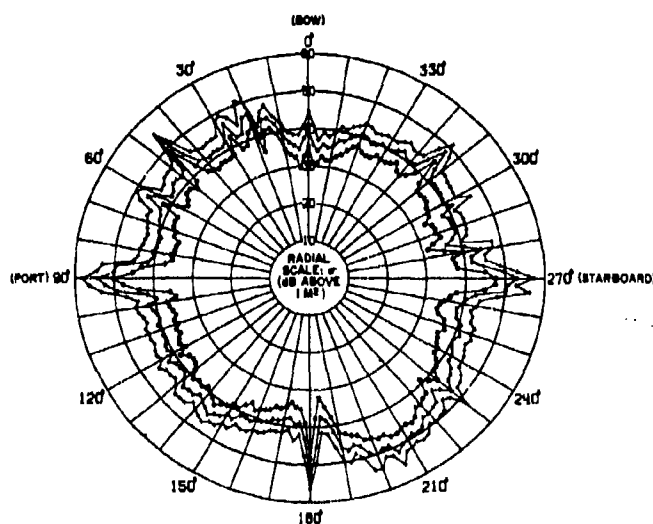at 2800 MHz for horizontal polarization

Fig. 25(C) - Radar cross section of the DE 1027
at 9225 MHz for horizontal polarization

Vertically polarized data at X band were not obtained
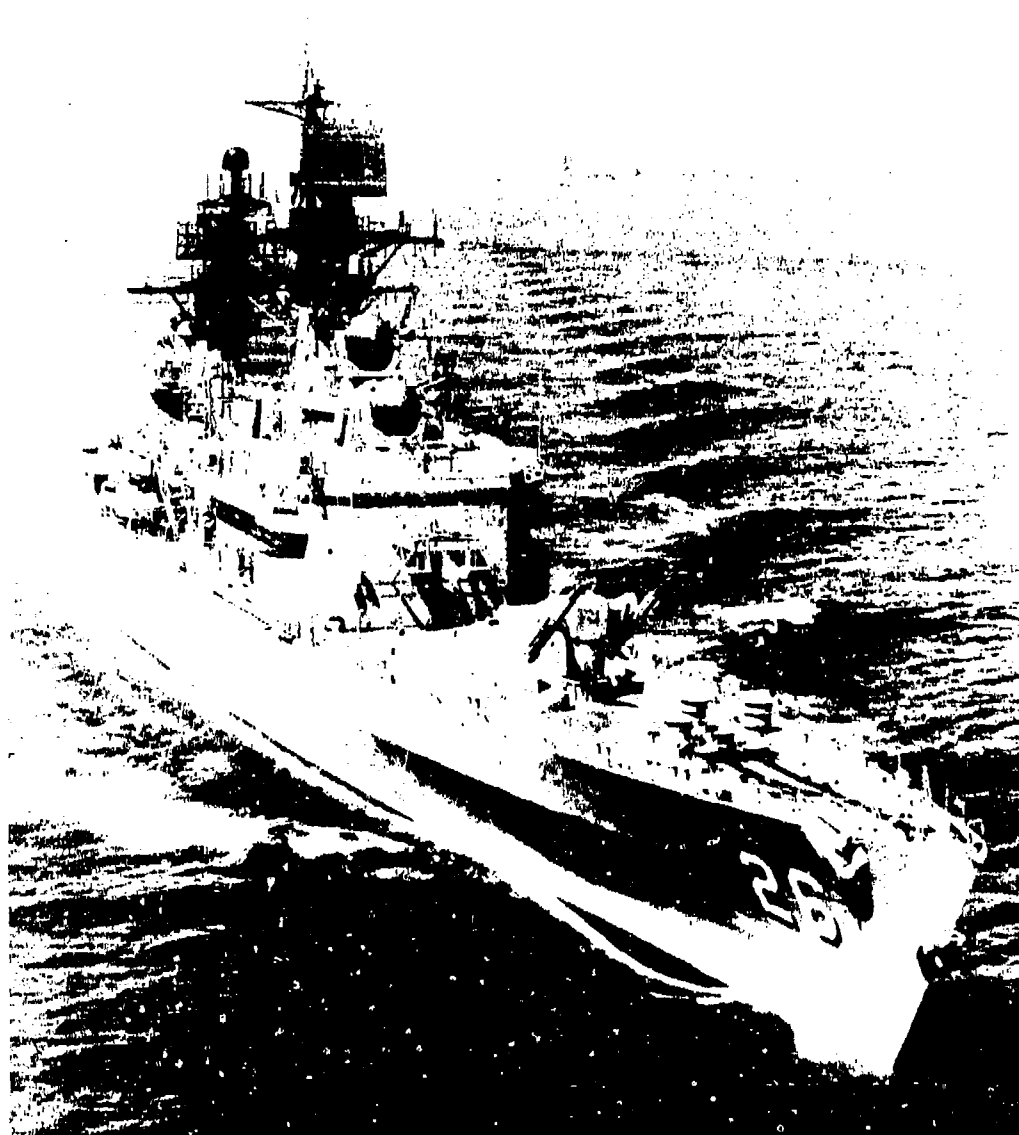due to deployment requirements placed on the ship.

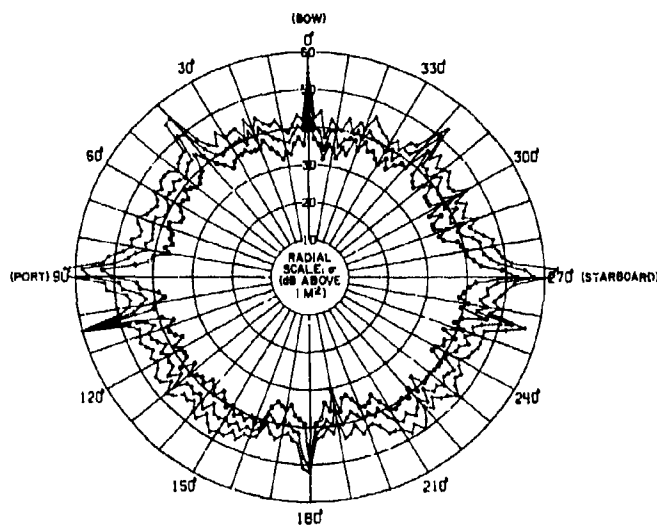Fig. 26(U) - U.S.S. *Belknap*, DLG 26

Fig. 27(C) - Radar cross section of the DLG 26 at 1300 MHz
for horizontal polarization. Shown are the 20, 50, and 80 per-
centile values of the RCS distribution function denoted by a
circle (○), a triangle (△), and a cross (+) respectively. The
direction of rotation during the measurement is CW, producing
an elevation angle of 0 degrees (static list of 1 degree minus
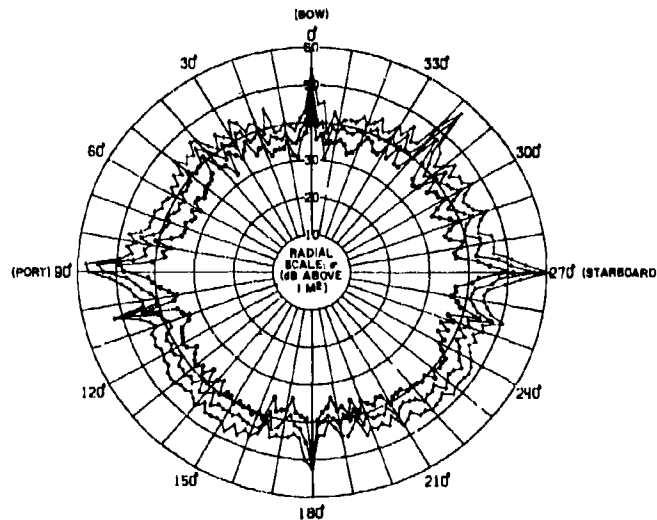a dynamic list of 1 degree).

Fig. 28(C) - Radar cross section of the DLG 26 at 1300 MHz
for horizontal polarization. The direction of rotation during
the measurement is CCW, producing an elevation angle of -2
degrees for the port side and +2 degrees for the starboard side
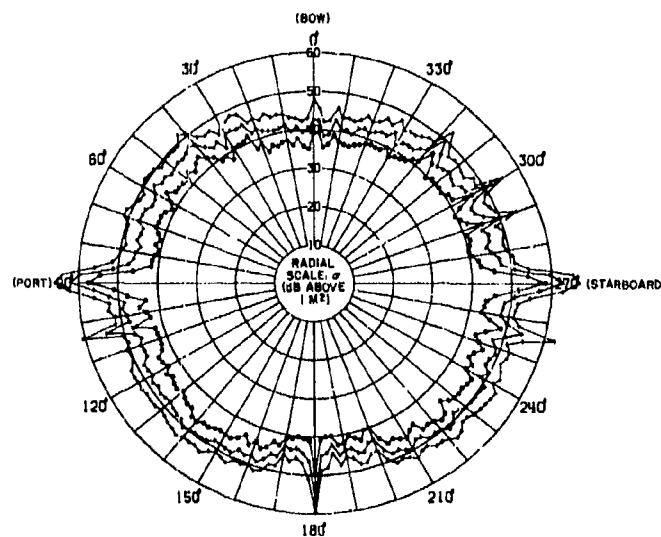(static list of 1 degree plus a dynamic list of 1 degree).

Fig. 29(C) - Radar cross section of the DLG 26 at 2800 MHz for horizontal polarization. The elevation angle is 0 degrees.
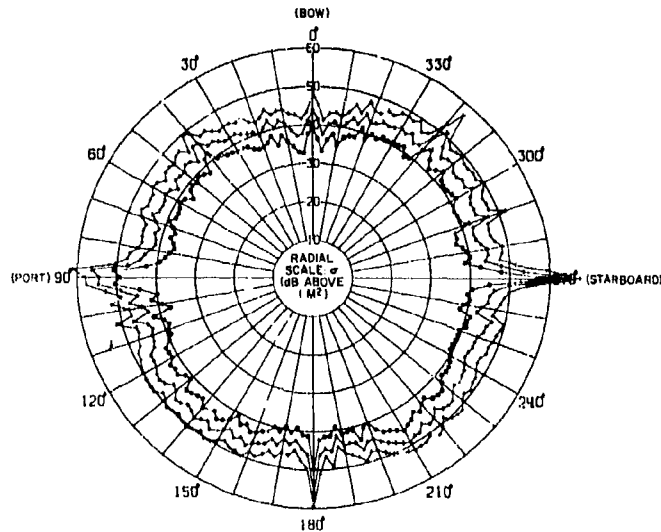

Fig. 30(C) - Radar cross section of the DLG 26 at 2800 MHz for horizontal polarization. The elevation angle is -2 degrees on the port side and +2 degrees on the starboard side.
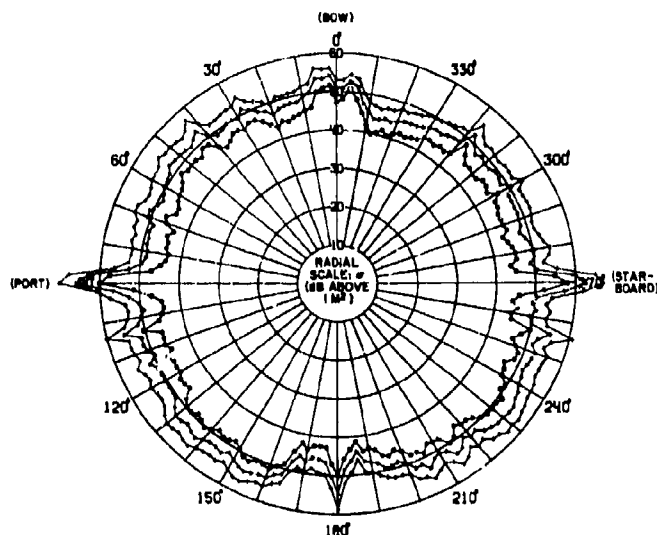
Fig. 31(C) - Radar cross section of the DLG 26 at 9225 MHz for horizontal polarization. The elevation angle is 0 degrees.
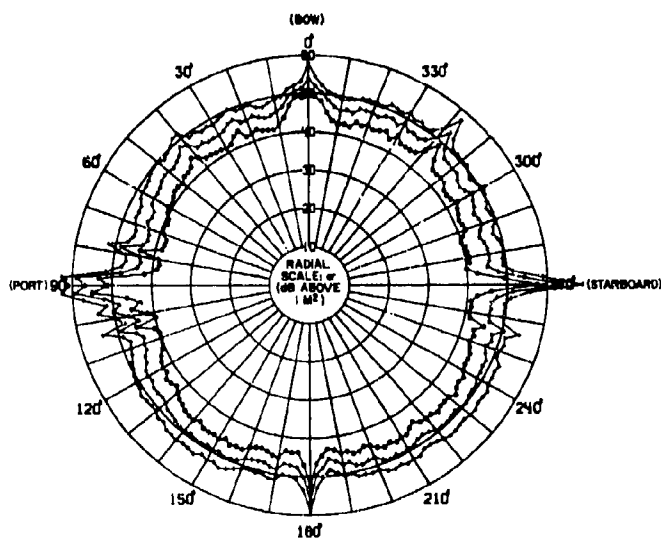

Fig. 32(C) - Radar cross section of the DLG 26 at 9225 MHz for horizontal polarization. The elevation angle is -2 degrees on the port side and +2 degrees on the starboard side.

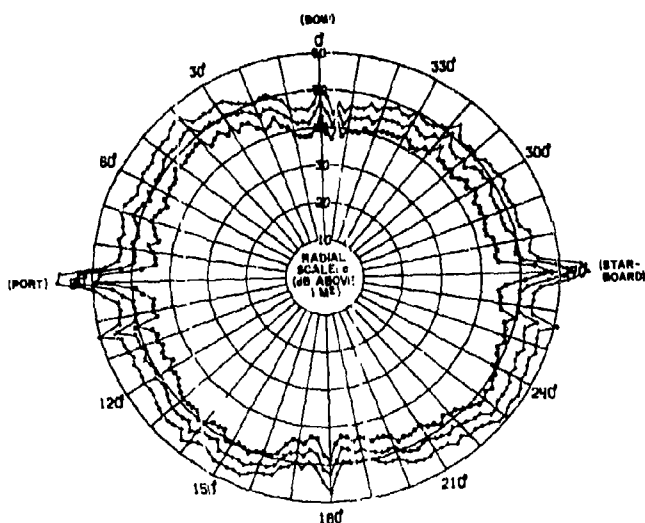CONFIDENTIAL

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Fig. 33(C) - Radar cross section of the DLG 26 at 9225 MHz
for vertical polarization. The elevation angle is 0 degrees.

Fig. 34(C) - Radar cross section of the DLG 26 at 9225 MHz
for vertical polarization. The elevation angle is -2 degrees on
the port side and +2 degrees on the starboard side.

Fig. 35(C) - Radar cross section of the DLG 26 at 5500 MHz
for horizontal polarization. The elevation angle is 0 degrees.

Fig. 36(C) - Radar cross section of the DLG 26 at 5500 MHz
for horizontal polarization. The elevation angle is -2 degrees
on the port side and +2 degrees on the starboard side.

Fig. 37(C) - Radar cross section of the DLG 26 at 5500 MHz for vertical polarization. The elevation angle is 0 degrees.
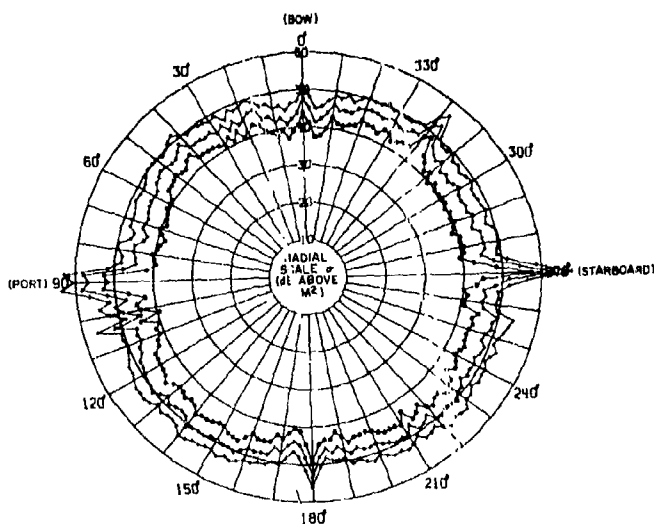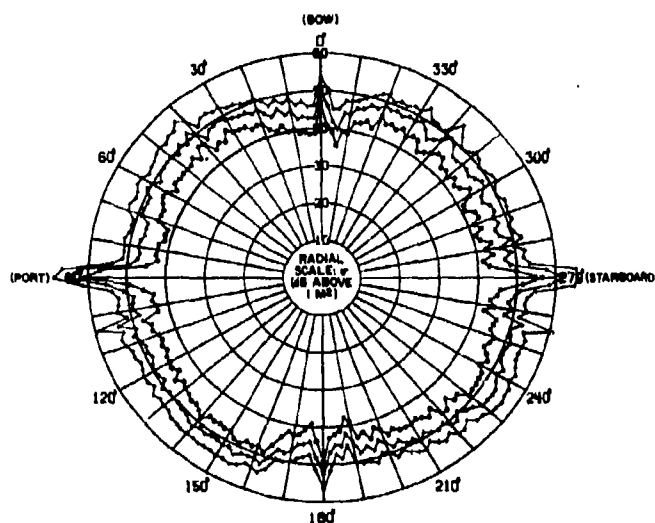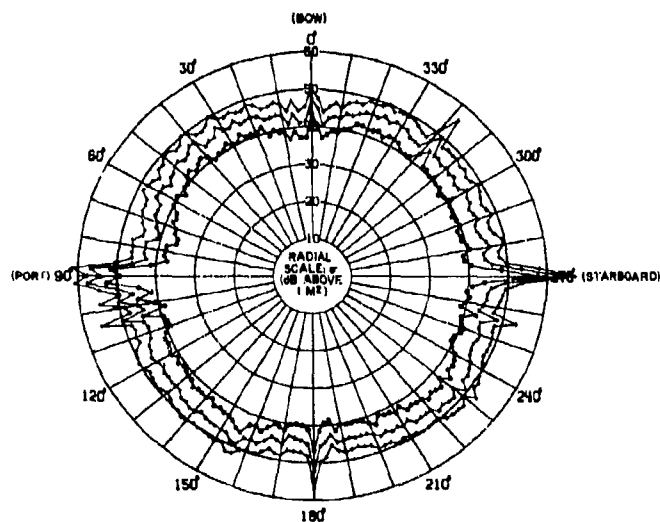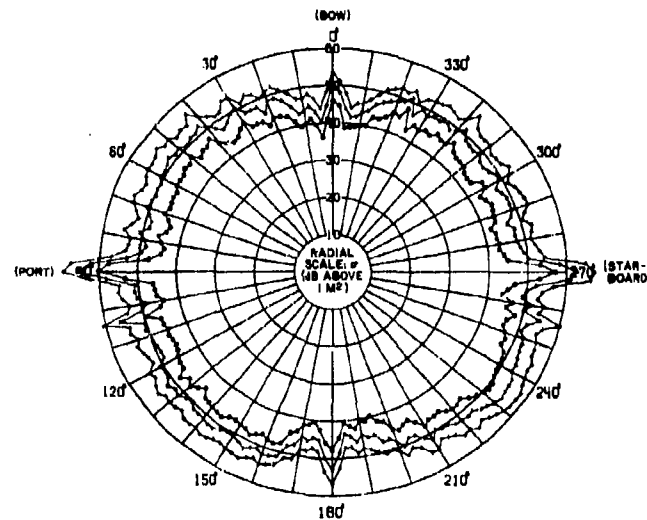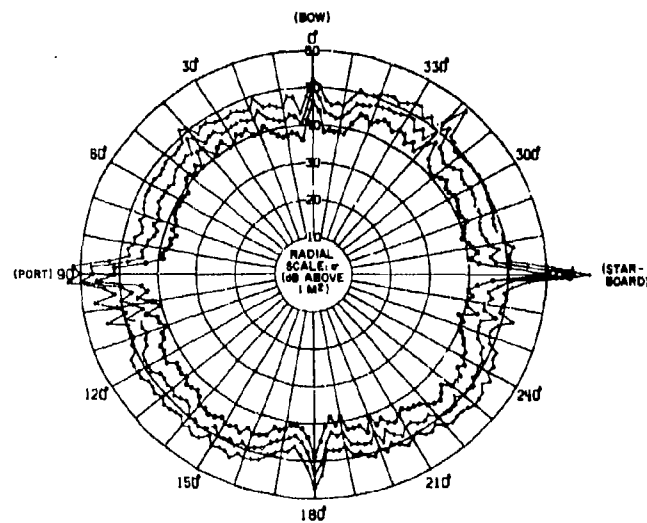
Fig. 38(C) - Radar cross section of the DLG 26 at 5500 MHz for vertical polarization. The elevation angle is -2 degrees on the port side and +2 degrees on the starboard side.
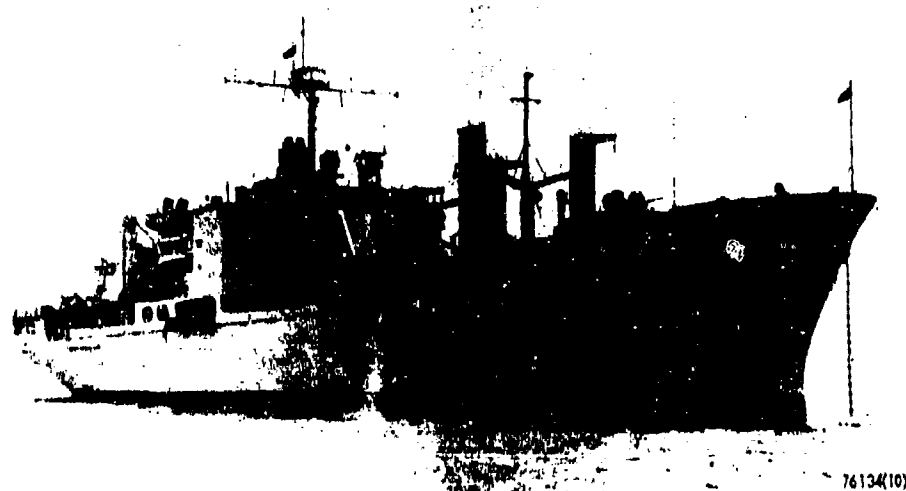
Fig. 39a(U) - U.S.S. *Concord*, AFS 5

Fig. 39b(U) - Port quarter view of the U.S.S. *Concord*, AFS 5
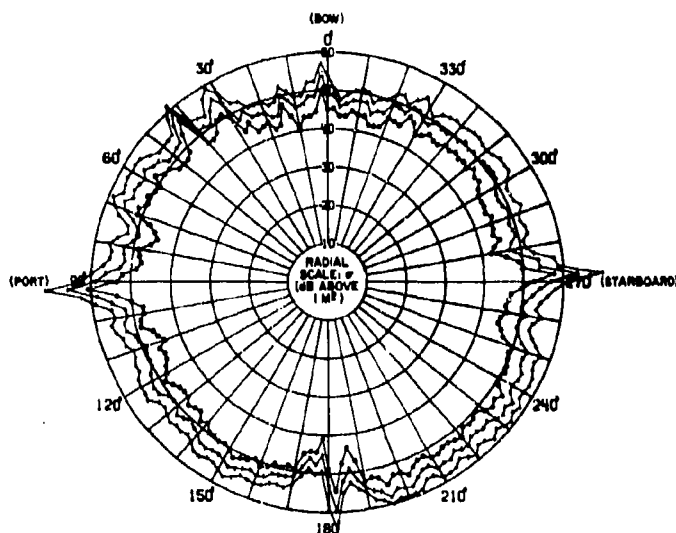
Fig. 40(C) - Radar cross section of the AFS 5 at 1300 MHz for horizontal polarization. Shown are the 20, 50, and 80 percentile values of the RCS distribution function denoted by a circle (○), a triangle (△), and a cross (+) respectively.
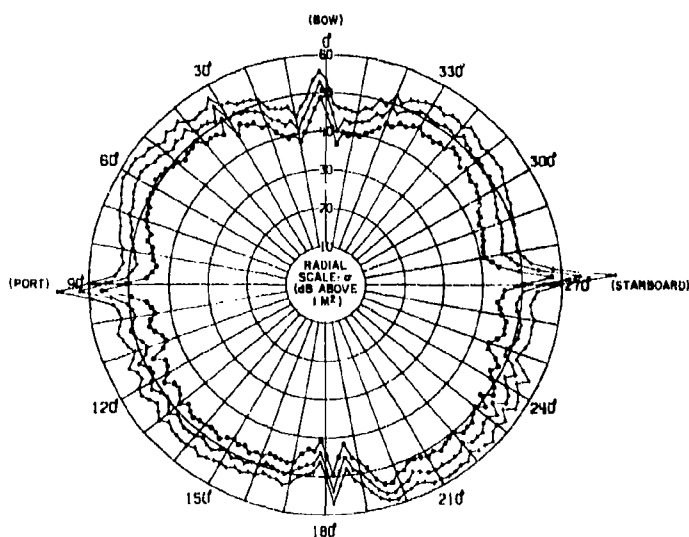
Fig. 41(C) - Radar cross section of the AFS 5 at 2800 MHz for horizontal polarization

Fig. 42(C) - Radar cross section of the AFS 5
at 9225 MHz for horizontal polarization

Fig. 43(C) - Radar cross section of the AFS 5
at 9225 MHz for vertical polarization

Fig. 44(C) · Radar cross section of the AFS 5
at 5500 MHz for horizontal polarization

Fig. 45(C) · Radar cross section of the AFS 5
at 5500 MHz for vertical polarization

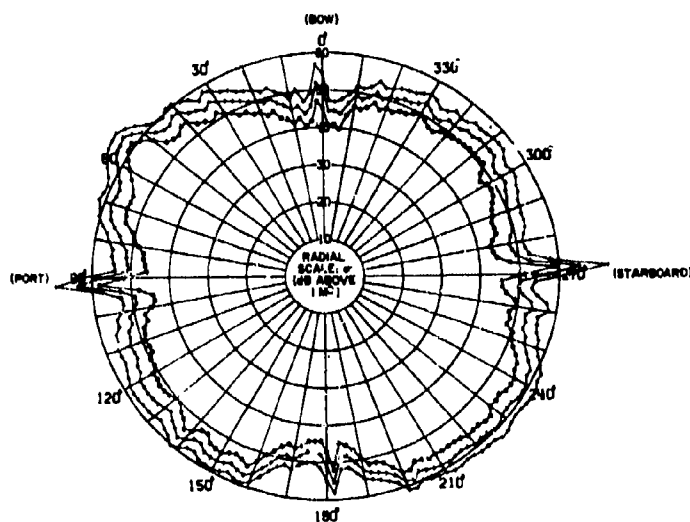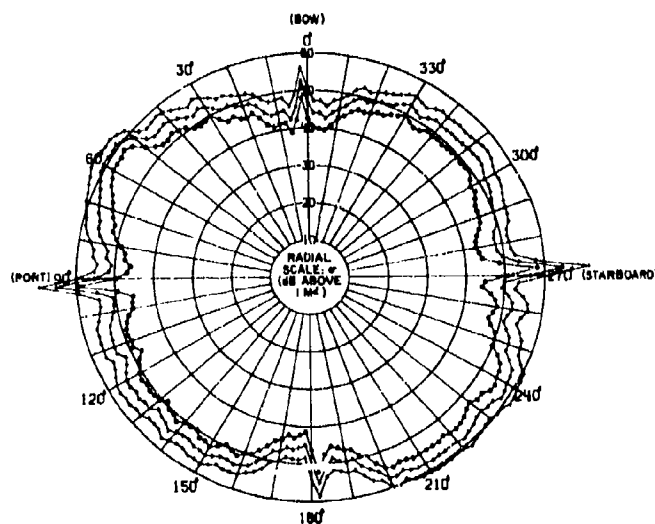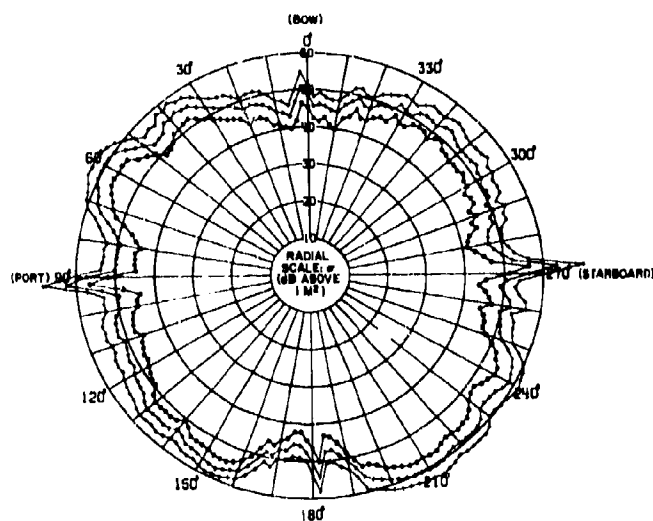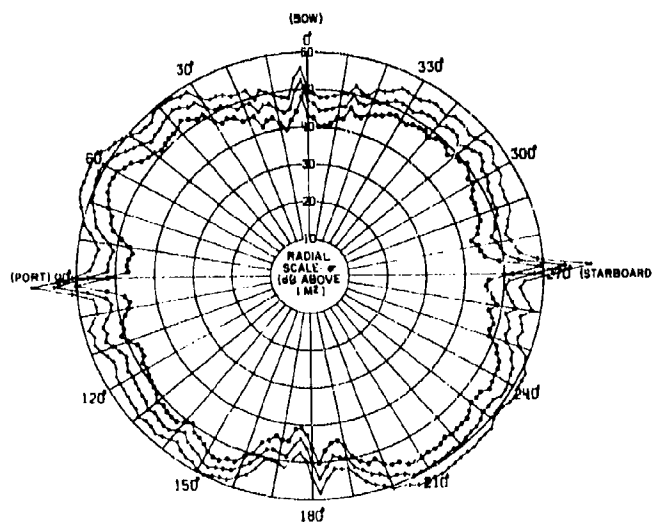## DOCUMENT CONTROL DATA - R & D

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RADAR CROSS SECTIONS OF SURFACE SHIPS AT GRAZING INCIDENCE [U]

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A final report on measurements made to date, with measurements to continue on additional ship classes.

5. AUTHOR(S) *(First name, middle initial, last name)*

F.D. Queen and E.F. Maine, Jr.

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13. ABSTRACT [Unclassified]

The radar-cross-section (RCS) values of seven classes of surface ships have been determined at grazing incidence at frequencies of 1300, 2800, and 9225 MHz for horizontal polarization and for vertical polarization at 9225 MHz. Measurements were performed at the Chesapeake Bay Division at NRL as the ships proceeded in a circular orbit. The ships used for the measurements were the DD 764, DEG 6, DDG 19, LPD 1, DE 1027, DLG 26, and AFS 5. In addition, measurements were made on the DLG and AFS in C band at 5500 MHz for both horizontal and vertical polarizations. Cross-section values were plotted as a function of ship aspect in the form of polar profiles. The profiles plotted were the 20, 50, and 80 percentile values of the RCS distribution function, which were determined for 2-degree azimuth increments.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Ships Surface ship detection Radar cross sections Destroyers (DD) Destroyer escorts (DE) Guided-missile destroyers (DDG) Guided-missile destroyer leaders (DLG) Combat store ships (AFS) Guided-missile escort ships (DEG) Amphibious transport docks (LPD)						

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